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SPECIFICATION <EXCERPT>

[0026]

[Equation 3]

$X(t) = [x_1(t), x_2(t), \ldots, x_N(t)]^T$

[Equation 4] $Rxx=E\{X^A(t) \cdot X^T(t)\}$

[Equation 5] $V_kxr=E\{X^A(t) \cdot d_k(t)\}$

[0027] Here, in the equation 3, $[]^T$ expresses the transpose of a matrix. In the equation 5, k=1, 2, ..., L, and E{} expresses an average of a correlation vector between N-dimensional column vector X(t) and a training signal $d_k(t)$ during all periods of the training signal $d_k(t)$. That is, the correlation vector V_kxr expresses a degree of similarity between a training signal included in the receiving signal and a k-th training signal $d_k(t)$.

[0028] The beam forming device B1 consists of L beam selectors Ba-1 to Ba-L. The beam selector Ba-k (k= 1, 2, ..., L) consists of the multiplier 2-k-1 to 2-k-N, and an adder 3-k. In the beam selector Ba-1, a multiplier 2-1-s (s=1, 2, ..., N) outputs a signal generated by multiplication of received signal $x_s(t)$ and the complex weight w_{1s}, to the adder 3-1, and the adder 3-1 outputs signal $y_1(t)$ generated by adding a switch SW-1 to a sum of N signals outputted from multipliers 2-1-1 to 2-1-N. Thereby, the beam selector Ba-1 which consists of the multipliers 2-1-1 to 2-1-N and the adder 3-1 outputs signal $y_1(t)$ received by a direct wave, to a switch SW-1.

[0029] In the beam selector Ba-2, a multiplier 2-2-s (s=1, 2, ..., N) outputs a signal generated by multiplication of a received signal $x_s(t)$ by the complex weight w_{2s}, to the adder 3-2, and the adder 3-2 outputs a signal $y_2(t)$ which is generated by adding N signals

outputted from multipliers 2-2-1 to 2-2-N, to the switch SW-2. Thereby, the beam selector Ba-2 which consists of the multipliers 2-2-1 to 2-2-N and the adder 3-2 outputs a signal $y_2(t)$ received by the first delayed wave, to a switch SW-2. Similarly, the beam selector Ba-k (k=1, 2, ..., L) which consists of the multipliers 2-k-1 to 2-k-N and the adder 3-k outputs a signal $y_k(t)$ received by the (k-1)-th delayed wave, to a switch SW-k.

[0030] The signal selector 4 consists of switches SW-1 to SW-L. In the signal selector 4, the switch SW-k opens and closes each transmission line based on the command signal Sk outputted from the adaptive control processor 9. Namely, when a size of the correlation vector $V_k$xr is larger than a predetermined threshold value, the switch SW-k is closed to transmit the signal $y_k(t)$. ON the other hand, when a size of the correlation vector $V_k$xr is less than a predetermined threshold value, the switch SW-k is opened no to transmit the signal $y_k(t)$. Thus, the signal selector 4 which consists of the switches SW-1 to SW-L selects, from among signals $y_1(t)$ to $y_L(t)$ outputted from the beam selectors Ba-1 to Ba-L, a signal having a size of the corresponding correlation vector larger than a predetermined threshold value, and outputs the signal to the multipliers 5-1 to 5-L.

[0031] Multipliers 5-k (k=1, 2, ..., L) performs multiplication of the signal outputted from the beam selector 3-k and inputted via the switch SW-k by an electric power weighting factor $1/|Wk|^2$ inputted from the adaptive control processor 9, and outputs the result to the adder 6. Here, as shown in Equation 2, since a weight vector W_k is proportional to an inverse number of the autocorrelation matrix Rxx, namely, an inverse number of electric power, a weight vector W_k corresponding to a received wave having large receiving electric power is decreased. As a result, electric power of the signal $y_k(t)$ having a large receiving electric power among signals $y_k(t)$ outputted from the signal selectors 4 can be further increased, and

electric power of the signal $y_k(t)$ having a small receiving electric power can be further decreased. The adder 6 adds two or more signals outputted from the multipliers 5-1 to 5-L, and outputs them to the maximum likelihood estimation device 7. That is, a control device of an array antenna according to the present embodiment performs the maximum ratio synthesis by which signals are synthesized with the greatest ratio by the multipliers 5-1 to 5-L and the adder 6. Thereby, a signal-to-noise ratio (S/N ratio) is made to the maximum.

[0032] The maximum likelihood estimation device 7 consists of: a ROM (not shown) in which a program of the maximum likelihood estimation processing is stored; a CPU (not shown) which performs the maximum likelihood estimation processing, and presumes and outputs a digital signal included in a received signal; and a memory storage (not shown). The maximum likelihood estimation device 7 performs the maximum likelihood estimation processing as described later, based on the signal yt outputted from the adder 6 and the electric power weighting factor $1/|Wk|^2$ outputted from the adaptive control processor 9, and thereby estimates a digital signal included in the received signal and outputs the result to the demodulator 8. The demodulator 8 performs demodulation on the digital signals outputted from the maximum likelihood estimation device 7, and outputs a baseband signal.

[0033] Operations of the control device of the array antenna having the above structure is explained. Each received signal received by the antenna elements 100-1 to 100-N of the array antenna 100 includes, as shown in FIG. 2(a): a sent signal including a direct wave and the first to the (L-1)th delayed waves; and unnecessary waves such as inter-channel interference waves C1, C2, C3, and the like. Here, the inter-channel interference waves are signals other than the sent signals having the same frequency as the sent signal. Respective received signals received by the antenna elements 100-1

to 100-N are changed into the respective received signals R1 to RN by the receiving modules RM-1 to RM-N, then applied with in-phase distribution by the in-phase distributors 1-1 to 1-N, and inputted into the beam forming device B1.

[0034] Received signal $x_1(t)$ to $x_N(t)$ inputted into the beam forming device B1 are converted by the beam forming device B1 into signal $y_1(t)$ received by a direct wave and signals $y_2(t)$ to $y_L(t)$received by the first to the (L-1)th delayed wave, and then outputted. Here, from the signals outputted from the beam forming device B1, as shown in FIG. 2(b), the unnecessary waves of the inter-channel interference waves C1, C2, C3, and the like are removed. From among the signals $y_k(t)$ outputted from the beam forming device B1, a signal whose corresponding correlation vector $V_k$xr has a size larger than a predetermined threshold value is outputted from the signal selector 4, then multiplied by the electric power weighting factor $1/|W_k|^2$ using the multiplier 5-k, and then outputted to the adder 6. The signals outputted from the multiplier 5-k are added together by the adder 6, and outputted to the maximum likelihood estimation device 7.

[0035] FIG. 2 (c) shows one example of the signal outputted from the adder 6. For example, as shown in FIG. 2(c), from among the signals outputted from the beam forming device B1 of FIG. 2 (b), a signal $y_3(t)$ whose corresponding correlation vector V_3xr has a size less than the predetermined threshold value is not outputted from the signal selector 4 as described above. Thereby, the signal $y_3(t)$ is not outputted from the adder 6. From among the signals $y_1(t)$ to $y_L(t)$ outputted from the beam forming device B1 shown in FIG. 2 (b), signals $y_1(t)$, $y_2(t)$, $y_4(t)$, and $y_L(t)$ corresponding to respective corresponding correlation vectors $V_k$xr each having a size less than the predetermined threshold value are multiplied by the electric power weighting factors $1/|W_1|^2$, $1/|W_2|^2$, $1/|W_4|^2$, $1/|W_L|^2$, respectively, then added together, and outputted to the adder 6.

Then, the digital signal included in the received signals is applied with the maximum likelihood estimation by the maximum likelihood estimation device 7 based on the signals yt and the electric power weighting factor $1/|W_k|^2$, then outputted, and modulated by the modulator 8, thereby outputting baseband signal.

[0036] Next, by (i) multiplying a weight vector W_1 calculated by the adaptive control processor 9 using the Equation 2 by (ii) the N-dimensional column vector X(t), it is possible to retrieve the signal $y_1(t)$ received by a direct wave. In addition, by multiplication of a weight vector $W_k(k=2, ..., L)$ calculated using Equation 2 by the adaptive control processor 9 by the N-dimensional column vector X(t), why a signal $y_k(t)$ received by the (k-1)th delayed wave can be retrieved is explained.

[0037] As mentioned above, the signal $y_k(t)$ outputted from the beam forming device B1 is a signal obtained by the generated by the multiplication of the weight vector W_k by the N-dimensional column vector X(t), and can be expressed by the following Equation 6.

[0038]

[Equation 6] $y_k(t) = W_k^T \cdot X(t)$

[0039] In the control device of the array antenna of the present embodiment, the training signal $d_k(t)$ generated by the signal generator 10 is the same as the training signal included in the sent signal. Therefore, by calculating the weight vector W_1 so that the waveform of the signal $y_1(t)$ received by the direct wave may be similar to the waveform of the training signal $d_1(t)$ as much as possible, the weight vector W_1 for retrieving the signal $y_1(t)$ received by the direct wave can be calculated. In addition, by calculating the weight vector W_k so that the waveform of the signal $y_k(t)$ (k=2, ..., L) received by the (k-1)th delayed wave may be similar to the waveform of the training signal $d_k(t)$ as much as possible, the weight vector W_k for retrieving the signal $y_k(t)$ received by the (k-1)th delayed wave can be calculated.

[0040] Namely, by calculating an instant square error ε_k^2 ($k=1, 2, \ldots, L$) which is obtained by calculating the square of the error signal ε_k defined by the following Equation 7 may become the minimum, a weight vector W_1 for retrieving the signal $y_1(t)$ received by the direct wave and a weight vector W_k for retrieving the signal $y_k(t)$ received by the (k-1)th delayed wave. Here, the second formula of the right-hand side in Equation 7 is obtained by substituting a formula of the Equation 6 to $y_k(t)$ of the first formula of the right-hand side. By calculating the square of the both sides of Equation 7, the instant square error ε_k^2 can be expressed by Equation 8. The root mean square error $E[\varepsilon_k^2]$ can be expressed by the following Equation 9.

[0041]

[Equation 7] ε_k

$=d_k(t)-y_k(t)$

$=d_k(t)-W_k^T \cdot X(t)$

[Equation 8] $\varepsilon_k^2=\{d_k(t)\}^2+W_k^T \cdot X(t) \cdot X^T(t) \cdot W_k-2d_k(t) \cdot X^T(t) \cdot W_k$

[Equation 9]$E[\varepsilon_k^2]=E[\{d_k(t)\}^2]+W_k^T \cdot E[X^A(t) \cdot X^T(t)] \cdot W_k-2E[X^A(t) \cdot d_k(t)]W_k$

[0042] Therefore, in order to calculate the weight vector W_1 corresponding to the direct wave and the weight vector W_k corresponding to the (k-1)th delayed wave, the weight vector W_k is calculated so that the root mean square error $E[\varepsilon_k^2]$ expressed by Equation 9 becomes the minimum. Here, $X^A(t)$ expresses the conjugate transposed matrix of the N-dimensional column vector X (t).

[0043]Next, if the root mean square error $E[\varepsilon_k^2]$ expressed by Equation 9 is transformed using the autocorrelation matrix Rxx expressed by Equation 4 and the correlation vector $V_k$xr expressed by Equation 5, the root mean square error E $[\varepsilon_k^2]$ can be expressed by the following Equation 10.

[0044]

[Equation 10] $E[\varepsilon_k^2]$
$= E[\{d_k(t)\}^2]+W_k^T \cdot Rxx \cdot W_k-2V_kxr \cdot W_k$

[0045] As obvious from Equation 10, the root mean square error $E[\varepsilon_k^2]$ expressed by Equation 10 can be expressed as the concave secondary curved surface about regarding complex weights w_{k1} to w_{kN}, so that the root mean square error $E[\varepsilon_k^2]$ certainly has the minimum and the differential coefficient method cam be applied in the curved surface of the root mean square error $E[\varepsilon_k^2]$. Therefore, the weight vector W_k which sets to 0 the differential quotient obtained by differentiating the root mean square error $E[\varepsilon_k^2]$ expressed by Equation 10 using each of the complex weights w_{k1} to w_{kN} minimizes the root mean square error $E[\varepsilon_k^2]$. Therefore, by setting to 0 the differential quotient by differentiating the right-hand side of Equation 10 using each of the complex weights w_{k1} to w_{kN}, a conditional equation for minimizing the root mean square error $E[\varepsilon_k^2]$ expressed by Equation 10 can be expressed by Equation 11.

[0046]

[Equation 11] $Rxx \cdot W_k-V_kxr=0$

[0047] In the adaptive control processor 9, Equation 2 used to calculate the weight vector W_k is obtained by transforming Equation 11 which is a conditional expression for minimizing the root mean square error $E[\varepsilon_k^2]$. That is, the weight vector W_k for minimizing the root mean square error $E[\varepsilon_k^2]$ can be calculated by calculating the weight vector W_k to satisfy Equation 2. In other words, by calculating the weight vector W_k to minimize the root mean square error $E[\varepsilon_k^2]$, it is possible to obtain the weight vector W_1 for retrieving and the signal $y_1(t)$ received by the direct wave and the weight vector W_k for the retrieving signal $y_k(t)$ received by the (k-l)th delayed wave (k= 2, 3, --, L).

[0048] Next, the maximum likelihood estimation processing in the maximum likelihood estimation device 7 is explained. In the

embodiment according to the present invention, the maximum likelihood estimation of the digital signal included in received signals is performed using the known Viterbi algorithm based on the signal yt outputted from the adder 6 and L electric power weighting factors $1/|W_k|^2$ outputted from the adaptive control processor 9. Here, the Viterbi algorithm is an algorithm for performing, based on an output signal of the transversal filter and the tap gain of the transversal filter, on a received symbol sequence transmitted via the channel which can be expressed by models using the transversal filter. In the present invention, the Viterbi algorithm is performed by associating the signal yt outputted from the adder 6 with the output signal of the transversal filter and associating the L electric power weighting factors $1/|W_k|^2$ outputted from the adaptive control processor 9 with the tap gain of the transversal filter. The number of taps of the transversal filter corresponds to the number of the signal $y_k(t)$ outputted from the signal selector 4.

[0049] Here, it is assumed in the following description that the signal selector 4 selects two signals which are the signal $y_1(t)$ received by a direct wave and a signal $y_2(t)$ received by the first delayed wave. Therefore, the signal yt inputted into the maximum likelihood estimation device 7 can be expressed by the following Equation 12. In Equation 12, the first term of the right-hand side is the signal outputted from the multiplier 5-1, and the second term of the right-hand side is the signal outputted from the multiplier 5-2.

[0050]

[Equation 12] $yt=(1/|W_1|^2) \cdot y_1(t)+(1/|W_2|^2) \cdot y_2(t)$

[0051] Here, it is assumed that a transmitting station transmits a sent signal which is obtained by digital modulation according to the digital signal including a transmission symbol sequence $\{a_n\}$, and that a time delay of the first delayed wave is a symbol period T. In the following description, it is assumed that the modulation method is set to $\pi/4$ shift QPSK. That is, each symbol a_n can be any one of

four symbol values P(1), P(2), P(3), and P(4). Here, when the time parameter n is even, a symbol value P(1)=(1, 0), a symbol value P(2)=(0, 1), a symbol value P(3)=(-1, 0), and a symbol value P(4)=(0, -1). On the other hand, when the time parameter n is odd, a symbol value P(1)=(1/п2, 1/п2), a symbol value P(2) =(-1/п2, 1/п2), a symbol value P(3)=(-1/п2, -1/п2), and a symbol value P(4)=(1/п2, -1/п2). Therefore, as shown in FIG. 10, each of the signal $y_1(t)$ received by the direct wave and the signal $y_2(t)$ received by the first delayed wave includes the reception symbol sequence $\{Ra_n\}$. The reception symbol included in the signal $y_2(t)$ is delayed only the symbol period T than reception symbol included in the signal $y_1(t)$. Therefore, the received signal Ry_n in the time parameter n of the signal yt inputted into the maximum likelihood estimation device 7 can be expressed by the following Equation 13. Here, the time parameter n expresses a time parameter which is increased by the symbol period T. In Equation 13, it is assumed that $h1=(1/|W_1|^2)$ and $h2=(1/|W_2|^2)$.

[0052]

[Equation 13] $Ry_n=h1 \cdot Ra_n+h2 \cdot Ra_{n-1}$

[0053] FIG. 3 is a flow chart of the main routine of the maximum likelihood estimation processing performed by the maximum likelihood estimation device 7. As shown in FIG. 3, in the maximum likelihood estimation processing, in Step S1, the time parameter n and the not-judged symbol parameter K are initialized to 1, respectively, and it proceeds to Step S2. In Step S2, metric and path history initial-value-setting processing are performed, and it proceeds to Step S3. Here, in Step S2, path metric PM(m), branch metric BM(m, 1), and path history PHmem(m, 1) are set to initial values, respectively, se described later. In Step S3, n+1 is substituted to the time parameter n, and K+1 is substituted to the not-judged symbol parameter Next, in Step S4, branch metric and path history computation are performed, and it proceeds to Step S5.

Here, in Step S4, branch metric BM(m, x) is calculated, and the path history PHmem (m, 1) and the branch metric BMmem (m, 1) are set, as described later. In Step S5, branch metric and path history memory processing are performed, and it proceeds to Step S6. Here, in Step S5, the path history PHmem (i, j) and the branch metric BMmem (i, j) are set and memorized, as described later. In Step S6. path metric PM(m) calculation is performed, in other words, the path metric PM(m) is calculated as described later, and the processing proceeds to Step 7. In Step 7, reception symbol decision processing is performed, namely, a reception symbol is judged as described later, and the processing proceeds to Step S8. In Step 8, it is judged whether or not the received signals have been completed, and if the received signals have been completed, the maximum likelihood estimation processing is completed. On the other hand, if the received signals have not yet been completed, the processing proceeds to Step S3 and processing of Steps S4, S5, S6, and S7 is repeated.

[0054] That is, in the maximum likelihood estimation processing, processing from Steps S3 to Step S6 is repeated every symbol period T. In other words, every time one reception symbol Ra_n is received, processing from Steps S3 to Step S7 is repeated.

[0055] Next, subroutines of the metric and path history initial-value-setting processing as shown in Step 2 of FIG. 3 are explained in detail with reference to FIG. 4. In the subroutine, by substituting a symbol parameter at the head of a reference symbol sequence stored in the ROM 11 to the path metric parameter X in Step S201, thereby setting the path metric parameter X. Next, in Step S202, the direct wave symbol parameter m is initialized to 1, and in addition, in Step S203, the path metric parameter X is substituted for the path history PHmem(m, 1) thereby setting the path history PHmem(m, 1), and the processing proceeds to Step S204. In Step S204, it is judged whether m=X. If m=X, the

processing proceeds to Step S205. On the other hand, if m is not X, the processing proceeds to Step S207. In Step S205, 0 is substituted for the path metric PM(m) thereby setting the path metric PM(m). In Step 206, 0 is substituted for a branch metric BMmem(m, 1) thereby setting the branch metric BMmem(m, 1). After that, the processing proceeds to Step S209. In Step S207, a processing maximum value is substituted for the path metric PM(m) thereby setting the path metric PM(m). In Step S208, a processing maximum value is substituted for the branch metric BMmem(m, 1) thereby setting the branch metric BMmem(m, 1). After that, the processing proceeds to Step S209. Here, the processing maximum value is the maximum number that can be used in the processing. Further, in Step S209, m+1 is substituted for the direct wave symbol parameter m, and in Step S210, it is judged whether the direct wave symbol parameter m> 4. If the direct wave symbol parameter m> 4, the processing returns to the main routine. On the other hand, if not, the processing returns to Step S203.

[0056] In other words, in Step S2, if the direct wave symbol parameter m=X, both of the path metric PM(m) and the branch metric BMmem(m, 1) are set to 0, respectively, as a possible minimum value for the path metric PM(m) and the branch metric BMmem(m, 1). On the other hand, if the direct wave symbol parameter m is not X, both of the path metric PM(m) and the branch metric BMmem(m, 1) are set to a processing maximum value, respectively, as a possible maximum value for the path metric PM(m) and the branch metric BMmem(m, 1). As described above, both of the path metric PM(m) and the branch metric BMmem(m, 1) in the case of the time parameter n=1 are initialized to 0 or the processing maximum value, respectively, so that the judgment of the received symbol when the time parameter n=2 can be performed correctly.

[0057] Next, the subroutines of the branch metric and path history

calculation processing in Step S4 of FIG. 4 are described in more detail with reference to FIG. 5. In the subroutine, in Step S410, the direct wave symbol parameter m is set to 1, and in Step S402, it is judged whether the not-judged symbol parameter K> 1. If the not-judged symbol parameter K> 1, the processing proceeds to Step S403. On the other hand, if not, the processing proceeds to Step S404. In Step S403, for each value of the symbol parameter i=1, 2, 3 and 4 and the update parameter j= 1, ..., K-1, the branch metric BMmem (i, j) is substituted for the branch metric BMtmp (i, j), thereby temporarily storing the branch metric BMmem (i, j). For each value of the symbol parameter i=1, 2, 3 and 4 and the update parameter j=1, ..., K-1, the path history PHmem (i, j) is substituted for the path history PHtmp (i, j), thereby temporarily storing the path history PHmem (i, j). After that, the processing proceeds to Step S404. Here, the branch metric BMtmp (i, j) and the path history PHtmp (i, j) indicate locations in the storage device in which the branch metric BMmem (i, j) and the path history PHtmp (i, j) necessary for estimation of the received symbol at time are stored temporarily, respectively. Next, in Step S404, using the following Equation 14, a branch metric BM (m, x) for each value of the delayed wave symbol parameter x=1, 2, 3, and 4 at time parameter n.

[0058]

[Equation 14] $BM(m, x) = |Ry_n - \{h1 \cdot P(m) + h2 \cdot P(x)\}|$

FIG. 2

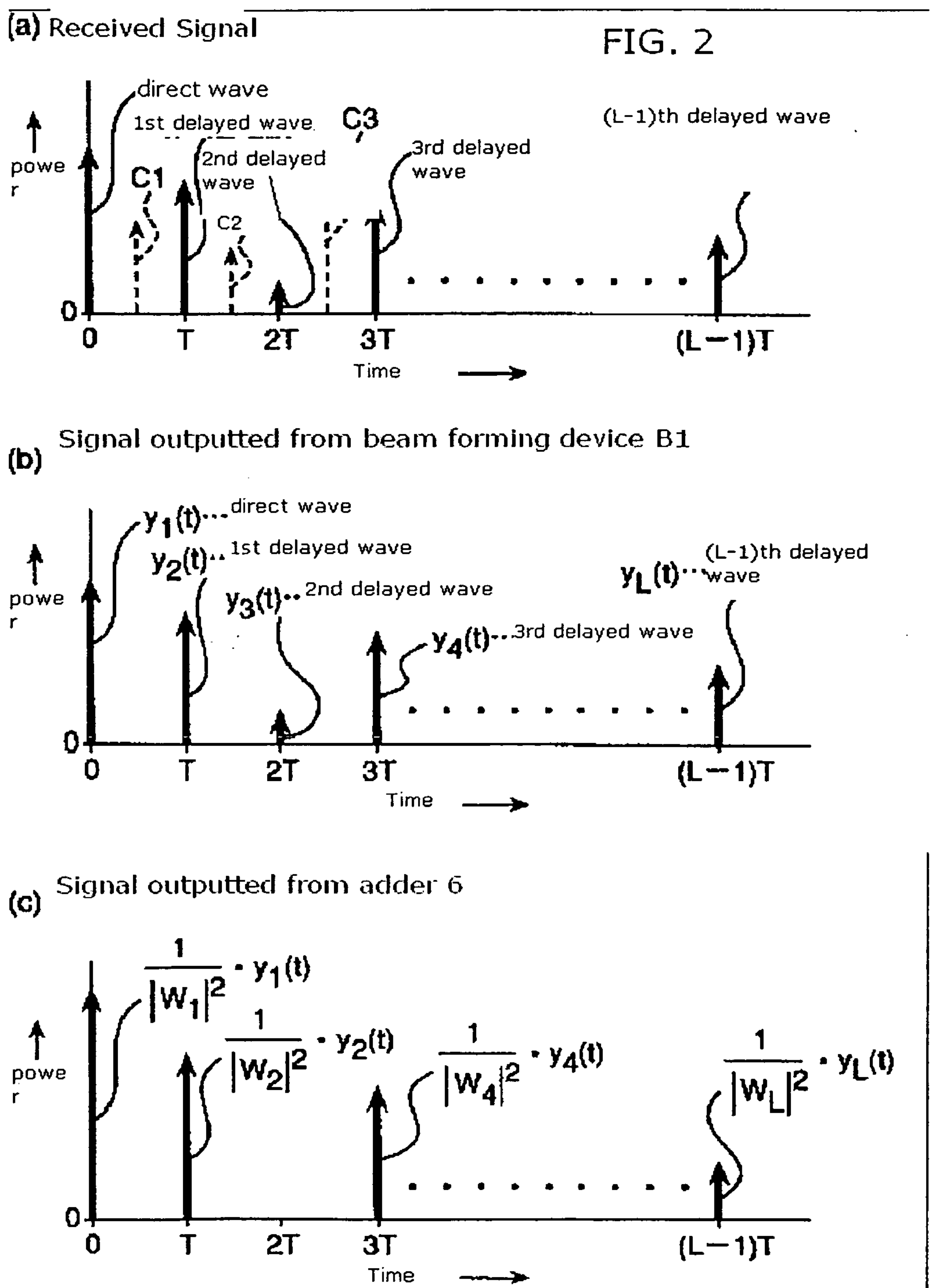
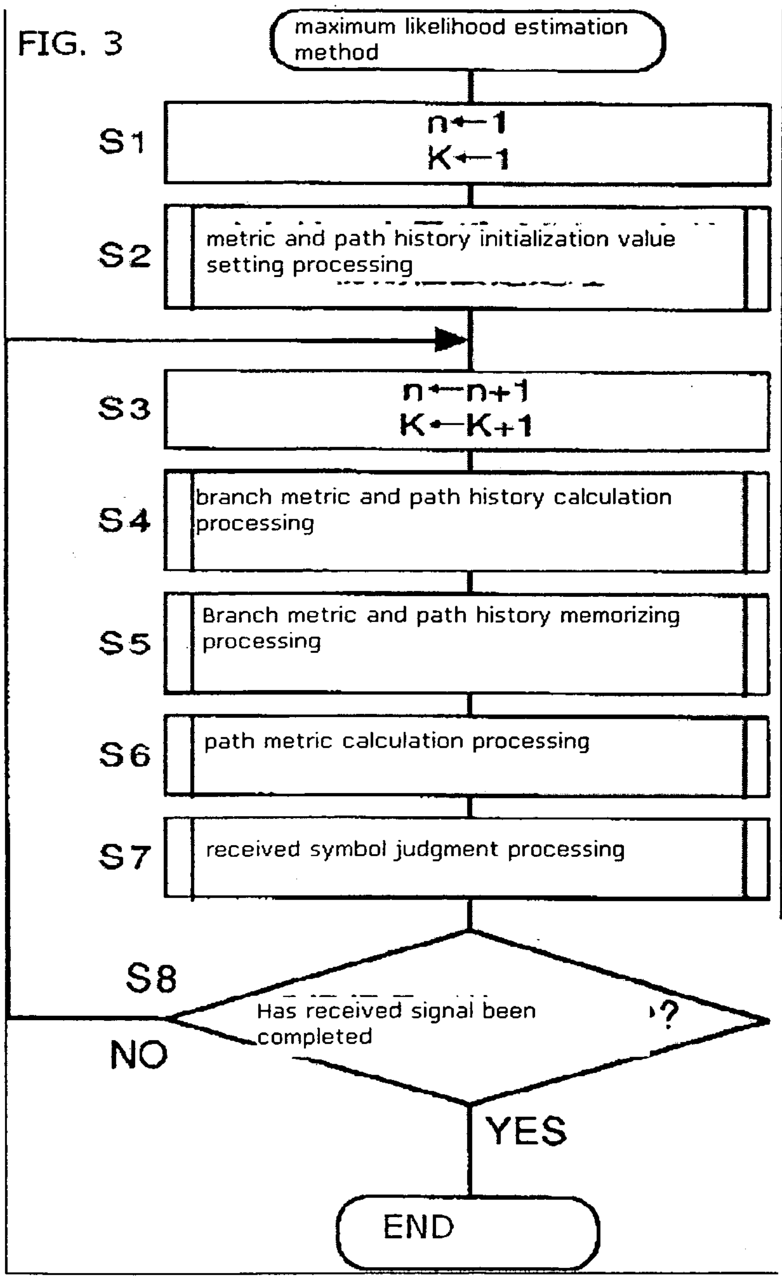

(a) Received Signal
power
direct wave
1st delayed wave
C1
2nd delayed wave
C2
C3
3rd delayed wave
(L-1)th delayed wave
0
0
T
2T
3T
(L−1)T
Time
(b) Signal outputted from beam forming device B1
power
y1(t)...direct wave
y2(t)..1st delayed wave
y3(t)..2nd delayed wave
y4(t)..3rd delayed wave
yL(t)..(L-1)th delayed wave
0
0
T
2T
3T
(L−1)T
Time
(c) Signal outputted from adder 6
power
1/|W1|^2 · y1(t)
1/|W2|^2 · y2(t)
1/|W4|^2 · y4(t)
1/|WL|^2 · yL(t)
0
0
T
2T
3T
(L−1)T
Time

FIG. 3



maximum likelihood estimation method
S1
n←1
K←1
S2
metric and path history initialization value setting processing
S3
n←n+1
K←K+1
S4
branch metric and path history calculation processing
S5
Branch metric and path history memorizing processing
S6
path metric calculation processing
S7
received symbol judgment processing
S8
Has received signal been completed ?
NO
YES
END